AECOM

Environment

Submitted to:
PacifiCorp

Submitted by:
AECOM
Fort Collins, Colorado
September 2017

Photochemical Modeling Protocol to Assess Visibility Impacts for PacifiCorp Power Plants located in Utah

List of Acronyms

AGL	above ground level
BART	Best Available Retrofit Technology
BC	boundary conditions
CAIR	Clean Air Interstate Rule
CAMD	Clean Air Market Division
CAMx	Comprehensive Air Quality Model with Extensions
CB0r2	Carbon Bond version6
CBNG	Coalbed Natural Gas
CEM	continuous emissions monitoring
CEMPD	Center for Environmental Modeling for Policy Development
CFR	Code of Federal Regulations
CMAQ	Community Multiscale Air Quality
CO	carbon monoxide
CSAPR	Cross-State Air Pollution Rule
dv	Deciview
DVC	Current Design Value
DVF	Future Year Design Value
EGU	Electric Generating Unit
EIS	Environmental Impact Statement
FIP	Federal Implementation Plan
FLAG	Federal Land Manager's Air Quality Guidance
ft	feet
ft/s	feet per second
HONO	nitrous acid
IC	initial conditions
IE	Institute for the Environment
IMPROVE	Interagency Monitoring of Protected Visual Environments
ISORROPIA	inorganic aerosol thermodynamics/partitioning model
K	Kelvin
km	kilometer
K_v	coefficient of vertical eddy diffusion
LCC	Lambert Conformal Conic
LNB	Low-NO_x Burners controls
m	meters
m/s	meters per second
m^2/s	square meters per second
MATS	Modeled Attainment Test Software
mb	millibar
MCIP	Meteorology-chemistry interface processor
MEGAN	Model of Emissions of Gases and Aerosols from Nature
MOVES	Motor Vehicle Emission Simulator

MOZART	Model for Ozone and Related chemical Tracers
MPE	model performance evaluation
MSL	mean sea level
NAAQS	National Ambient Air Quality Standards
NCAR	National Center for Atmospheric Research
NCL	NCAR Command Language
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NH_3	ammonia
NO	nitric oxide
NO_2	nitrogen dioxide
NONROAD	Non-road mobile emissions model
NO_X	oxides of nitrogen
NP	National Park
NPRI	National Pollutant Release Inventory
O_3	ozone
OFA	Over-fire Air controls
PAVE	Package for Analysis and Visualization of Environmental data
PBL	planetary boundary layer
PFT	plant functional types
PGM	photochemical grid model
PiG	Plume-in-Grid
PM	particulate matter
PM_{10}	PM with an aerodynamic diameter less than or equal to 10 microns
$PM_{2.5}$	PM with an aerodynamic diameter less than or equal to 2.5 microns
PPM	piecewise parabolic method
PSAT	Particulate Source Apportionment Technology
PSD	Prevention of Significant Deterioration
QA	quality assurance
RADM	Regional Acid Deposition Model
RPO	Regional Planning Organization
RRF	Relative Response Factors
SCC	Source Classification Code
SCR	Selective Catalytic Reduction controls
SIP	State Implementation Plan
SMAT-CE	Software for Model Attainment Test – Community Edition
SMOKE	Sparse Matrix Operator Kernel Emissions
SO_2	sulfur dioxide
tpy	tons per year
TUV	total ultraviolet
U.S.	United States
UNC	University of North Carolina
USEPA	United States Environmental Protection Agency
UV	ultraviolet

VMT	vehicle miles traveled
VOC	volatile organic compound
WA	Wilderness Area
WAQS	Western Air Quality Modeling Study
WBD	wind-blown dust
WRAP	Western Regional Air Partnership
WRF	Weather Research and Forecast

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1.0 Introduction

The United States Environmental Protection Agency (USEPA) issued a Regional Haze Rule to protect visibility in over 150 national parks and wilderness areas in 1999. The Regional Haze Rule requires states to establish Reasonable Progress Goals for improving visibility, with the overall goal of attaining natural background visibility conditions by 2064. On June 4, 2015, the State of Utah submitted to the USEPA a revised Regional Haze State Implementation Plan (SIP). The SIP addressed requirements of the Clean Air Act specifically related to the Regional Haze Rule. On July 5, 2015, USEPA approved some parts and disapproved other parts of Utah's regional haze SIP. Specifically, USEPA disapproved the State's nitrogen oxides (NO_x) Best Available Retrofit Technology (BART) determinations for PacifiCorp power plants Hunter units 1 and 2 and Huntington units 1 and 2. To address the portions of Utah's SIP that USEPA disapproved, USEPA finalized a Federal Implementation Plan (FIP) that determined NOx BART controls for Hunter and Huntington power plants require the application of selective catalytic reduction (SCR) controls with low NOx burners and separated overfire air (SCR + LNB/SOFA) (40 Code of Federal Regulations [CFR] Part 52 Vol. 81 No.128). The USEPA relied on the CALPUFF model to dismiss Utah State's SIP BART alternative; however CALPUFF uses high ammonia background concentrations that lead to unrealistically high visibility impacts from particulate nitrate associated to NOx emissions.

To address the source of these concerns, PacifiCorp is conducting an alternative modeling evaluation to assess the visibility benefits associated with alternative NOx emissions controls from Hunter and Huntington power plants combined with retiring the Carbon Power Plant. Results will be compared to the visibility benefits predicted by USEPA's proposed NOx BART limits. To conduct this assessment, PacifiCorp plans to perform photochemical grid modeling to predict the visibility impacts at nine Prevention of Significant Deterioration (PSD) Class I areas within 300 kilometers (km) of Hunter and Huntington. Several NOx control options will be evaluated, including emissions controlled in accordance with USEPA's FIP and emissions controlled in accordance with an alternative proposed by PacifiCorp.

AECOM has been retained by PacifiCorp to perform the agreed-upon modeling with the Comprehensive Air Quality Model with extensions (CAMx). CAMx is a photochemical grid model (PGM) with the capabilities to estimate the concentrations of pollutants that contribute to regional haze. It has a technical formulation that is considered more realistic than that of CALPUFF, and it is expected that CAMx would predict more accurate changes in light extinction as a result to changes in emissions from PacifiCorp power plants. This project would leverage an available CAMx modeling platform already reviewed by the USEPA and that covers the power plants and potentially affected nine Class I areas.

1.1 Model Description Overview

The use of the CAMx model for analyzing potential cumulative air quality impacts has been well established: the model has been used for many previous visibility modeling studies in the western U.S., including SIPs and Environmental Impact Statements (EISs). CAMx is a photochemical modeling system developed and updated regularly by Ramboll Environ Corporation. The Western Air Quality Study (WAQS) (IWDW 2016a and 2016b) will serve as the starting point to assess visibility impacts for different levels of emissions from PacifiCorp power plants. The WAQS is a modeling platform intended to facilitate air resource analyses for federal and state stakeholders as part of the National Environmental Policy Act (NEPA) process and also for other studies. The WAQS provides a framework for performing analyses that address air quality impacts in the three states of Wyoming, Colorado, and Utah.

The Intermountain West Data Warehouse (IWDW) developed an updated air quality model platform for WAQS year 2011 (referred to as "2011b") (IWDW 2016a and 2016b). The 2011b model platform includes updates to the emissions, boundary conditions and model configuration relative to its predecessor, the 2011a modeling platform. The 2011b model platform has been reviewed and approved by the IWDW-WAQS Cooperating Agencies, including USEPA (Region 8), the BLM (in Colorado, Wyoming, Utah and New Mexico offices), the FS (in Rocky Mountain, Intermountain, and Southwestern Regions), the NPS (intermountain region), and the FWS (region 6), CDPHE, WDEQ, UDEQ, and NMED For this study, AECOM will leverage and use the 2011b modeling platform and its individual components as described in this protocol.

The Weather Research and Forecast (WRF) Model and the Sparse Matrix Operator Kernel Emissions (SMOKE) model provide meteorological and emissions inputs respectively to the CAMx photochemical grid model. Collectively, these three models will be referred to hereafter as the CAMx modeling system The CAMx modeling system used for this project was selected for consistency with the WAQS and includes:

- WRF (version 3.5.1): State-of-science mesoscale numerical weather prediction system capable of supporting urban- and regional-scale photochemical, fine particulate and regional haze regulatory modeling studies.
- SMOKE (version 3.5.1): Emissions modeling system that generates hourly, gridded, and speciated emissions inputs of on-road, non-road, area, point, fire, and biogenic emissions sources for photochemical grid models.
- CAMx (version 6.10): State-of-science 'One-Atmosphere' photochemical grid model capable of addressing ozone and other criteria pollutants, visibility, and atmospheric deposition at the regional and urban scale.

The CAMx system will be configured to simulate the following modeling scenarios described in more detail in Chapter 2

- Typical Year Modeling Scenario The Typical scenario is used only to aid in the calculation of relative response factors that will be used for the visibility assessment impacts, as described in more detail in Chapter 4.0 This modeling scenario will include emissions for all the units of Carbon, Hunter and Huntington power plants at levels representative of the period 2001 to 2003, while all other sources will remain at the levels of the 2011 WAQS base year simulation
- Baseline Modeling Scenario The Baseline scenario will include the emission levels for all units of Carbon, Hunter and Huntington power plants that correspond to emissions representative of the period 2001 to 2003. All other emissions sources will remain at the levels of the 2025 WAQS future year simulation…
- USEPA FIP Modeling Scenario The USEPA FIP scenario will include the emission levels for all units of Hunter and Huntington power plants that correspond to the USEPA proposed FIP control strategy. The scenario also will include the Carbon power plant at the same level of emissions to the Baseline scenario. All other emissions sources will remain at the levels of the 2025 WAQS future year simulation
- PacifiCorp Modeling Scenario. The PacifiCorp scenario will include the emission levels for all units of Hunter and Huntington power plants that correspond to an alternative control strategy proposed by PacifiCorp. For this scenario, the Carbon power plant will be decommissioned and their emissions will be zero at both units. All other emissions sources will remain at the levels of the 2025 WAQS future year simulation

Notice that the only changes between the Baseline, USEPA FIP, and PacifiCorp scenarios are due to different emission rates for PacifiCorp power plants. All other regional sources will remain unchanged among all future year scenarios. For the 2011 the typical year scenario, the temporal profile of the PacifiCorp power plants emissions will be normalized to avoid any down time period for any of the units. This normalized temporal profile also will be used in the future year model simulations.

1.2 Final Deliverables

In addition to this modeling protocol, AECOM will provide a Final Visibility Assessment Report documenting the model configuration, emissions, and the findings from all the analyses performed.

1.3 Visibility Assessment Protocol Organization

Visibility impacts in this project will be evaluated using a three-step process:

- Estimate project emissions for all scenarios;
- Model the impacts resulting from the changes in these emissions; and
- Compare the modeled impacts among different scenarios.

The first step in the process is the emissions development. Chapter 2.0 identifies PacifiCorp power plants emissions, provides information on the regional emissions inventory and also shows the proposed modeling domains for this project. Chapter 3.0 details the modeling procedures. Chapter 4.0 outlines the procedures for reporting model results and comparing the resulting impacts among the different scenarios.

2.0 Emissions Inventories and Modeling Domains

The CAMx modeling system will be used to assess the visibility impacts associated with pollutants from PacifiCorp power plants that undergo long-range transport and chemical processes. Regional photochemical models need information from all emissions sources in the modeling domain, in addition to those associated with PacifiCorp power plants alone. This typically requires a comprehensive emissions inventory, which is processed in combination with the project-specific emissions.

The project-specific emissions will be provided by PacifiCorp and reviewed by USEPA, as described in Section 2.1. The methodology for developing a complete regional emissions inventory for the CAMx modeling is described in detail in Section 2.2.

2.1 PacifiCorp Power Plants Emissions

This section provides a description of the emission rates and parameters associated to the following PacifiCorp power plants located in Utah: Carbon, Hunter and Huntington. The modeling for this study will consider three different scenarios for the future year (2025) and an additional scenario for the typical year (2011). Each of the modeling scenarios emissions are described in more detail in the following sections. However, emissions associated to PacifiCorp power plants will be modeled using the same stack parameter information for all modeling scenarios. The stack parameters associated to each of PacifiCorp power plants units is summarized in **Table 2-1**. This information was provided by PacifiCorp and is identical to the information available in for the 2011 EPA National Emissions Inventory (NEI) version 6 (USEPA 2016) which was used in the WAQS

Table 2-1 Stack Parameters by Unit

Plant	Unit	Stack Height		Stack Diameter		Stack Exit Velocity		Stack Exit Temperature
		m	ft	m	ft	m/s	ft/s	K
Carbon	1	61.0	200.0	3.1	10.3	10.8	35.3	382.0
	2	52.4	172.0	3.8	12.5	12.1	39.8	412.6
Hunter	1	183.0	600.4	7.3	24.0	17.3	56.8	317.0
	2	183.0	600.4	7.3	24.0	17.3	56.8	317.0
	3	182.9	600.0	7.3	24.0	13.4	44.0	322.0
Huntington	1	183.0	600.4	7.3	24.0	19.6	64.3	317.0
	2	183.0	600.4	7.3	24.0	19.6	64.3	317.0

In addition to the stack parameters, all the scenarios will use identical values for the emissions speciation profile and the temporal profile for PacifiCorp power plants. The speciation profile will be based on the Carbon Bond version 6 (CB6r2) chemical mechanism with VOC, NO, NO_2, and $PM_{2.5}$ profiles using source specific speciation profiles developed with the SPECIATE 4.3 database. A detailed description of the temporal profile will be presented in the Typical Year scenario section (2.1.1)

2.1.1 Typical Year (2011) Modeling Scenario

The main goal of the Typical Year modeling is to aid in the calculation of relative response factors that will be used for the visibility assessment impacts, as described in more detail in Chapter 4.0. In general the Typical Year modeling Scenario regional emissions and configuration will be based on the WAQS 2011 platform with the exception that, the PacifiCorp power plants emissions for this modeling scenario will be representative of the period 2001 to 2003 instead of the measured emissions from year 2011. The annual emissions for PacifiCorp's power plants in tons per year (tpy) for the Typical Year Modeling Scenario are shown in **Table 2-2**.

The NO_x and SO_2 total annual emissions presented in **Table 2-2** are calculated from the three-year average (2001 to 2003) of emission rates found in the USEPA Clean Air Market Division (CAMD) emissions system for the PacifiCorp power plants (USEPA 2017a). In addition to NO_x and SO_2, **Table 2-2** includes emissions for these pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter (PM) with an aerodynamic diameter less than or equal to 10 microns (PM_{10}), PM with an aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$), and ammonia (NH_3). The annual emissions for pollutants not included in CAMD datasets are calculated from the 3-year average of years 2000 to 2002 for available data from the USEPA's National Emissions Inventory (NEI) (USEPA 2017b). The year 2003 was not included on this estimate because there is no NEI data for this year. However, the NEI did provide values for 2000 emissions which were similar in magnitude to those for years 2001 and 2002 and therefore are included in the final 3-year average estimate.

Table 2-2 PacifiCorp Power Plants Emissions for the Typical Year Modeling Scenario by Unit

Plant	Unit	NO_x tpy	SO_2 tpy	VOC tpy	CO tpy	PM_{10} tpy	$PM_{2.5}$ tpy	NH_3 tpy
Carbon	1	1,312.4	2,285.7	7.4	61.6	119.9	86.9	1.3
	2	1,977.3	3,527.5	11.3	93.9	182.9	132.5	1.9
Hunter	1	6,379.7	2,535.1	45.1	375.4	733.0	537.0	8.4
	2	6,092.1	2,531.4	44.1	367.5	717.4	525.5	8.2
	3	6,530.2	1,204.0	32.6	271.8	530.6	388.7	6.1
Huntington	1	5,944.3	2,380.4	28.3	235.8	517.2	331.1	4.9
	2	5,816.5	12,308.0	56.5	470.7	1,032.6	661.0	9.7

The total annual emissions must be temporally allocated throughout the year so that CAMx modeling can be performed. This allocation is referred as the emissions temporal profile. The temporal profile used for this and all other modeling scenarios was estimated with the objective to represent "a typical" level of operations for all the units from the PacifiCorp power plants during the 2001 to 2003 period (USEPA 2017a). The temporal profile was derived by taking the average of the CAMD daily SO_2 and NOx emissions from 2001 to 2012 for each power plant. This time period covers the entire time span of the emissions used for the various modeling scenarios considered. The Typical Year and Baseline Scenarios are based on emissions from 2001 to 2003, while the future year analysis, discussed in Chapter 4, is based on monitor data from 2010 to 2012. Using the average from eleven years also provides a temporal profile that retains a realistic day to day variability without fluctuations such as temporary shutdowns or restarts at each unit. The daily percentage contribution was then calculated by determining the percentage the 3-year daily contributes to the annual total. The resulting temporal profile for each power plant is shown in **Figure 2-1** as the daily percentage contribution for SO_2, NO_x and all the other pollutants. The SO_2 and NOx profiles will be applied to the SO_2 and NOx, emissions, respectively for each power plant's units. Notice that the temporal profile for all the other pollutants was determined through the average of the SO_2 and NO_x profiles and will be applied to the power plant's emissions for VOC, CO, PM_{10}, $PM_{2.5}$ and NH_3. In general the profiles show a fairly constant level of operations without a strong seasonality. For comparison a constant profile that allocates emissions equally throughout the year would represent a flat line at 0.27% every day.

A description of the regional emissions included in the modeling will be presented in Section 2.2. It is important to note that for this scenario all remaining Electric Generating Units (EGUs) emissions and temporal profiles will remain unchanged from the data provided by the 2011 WQAS modeling platform. In other words, the only changes to the emission inventory in this scenario are those described above for PacifiCorp power plants.

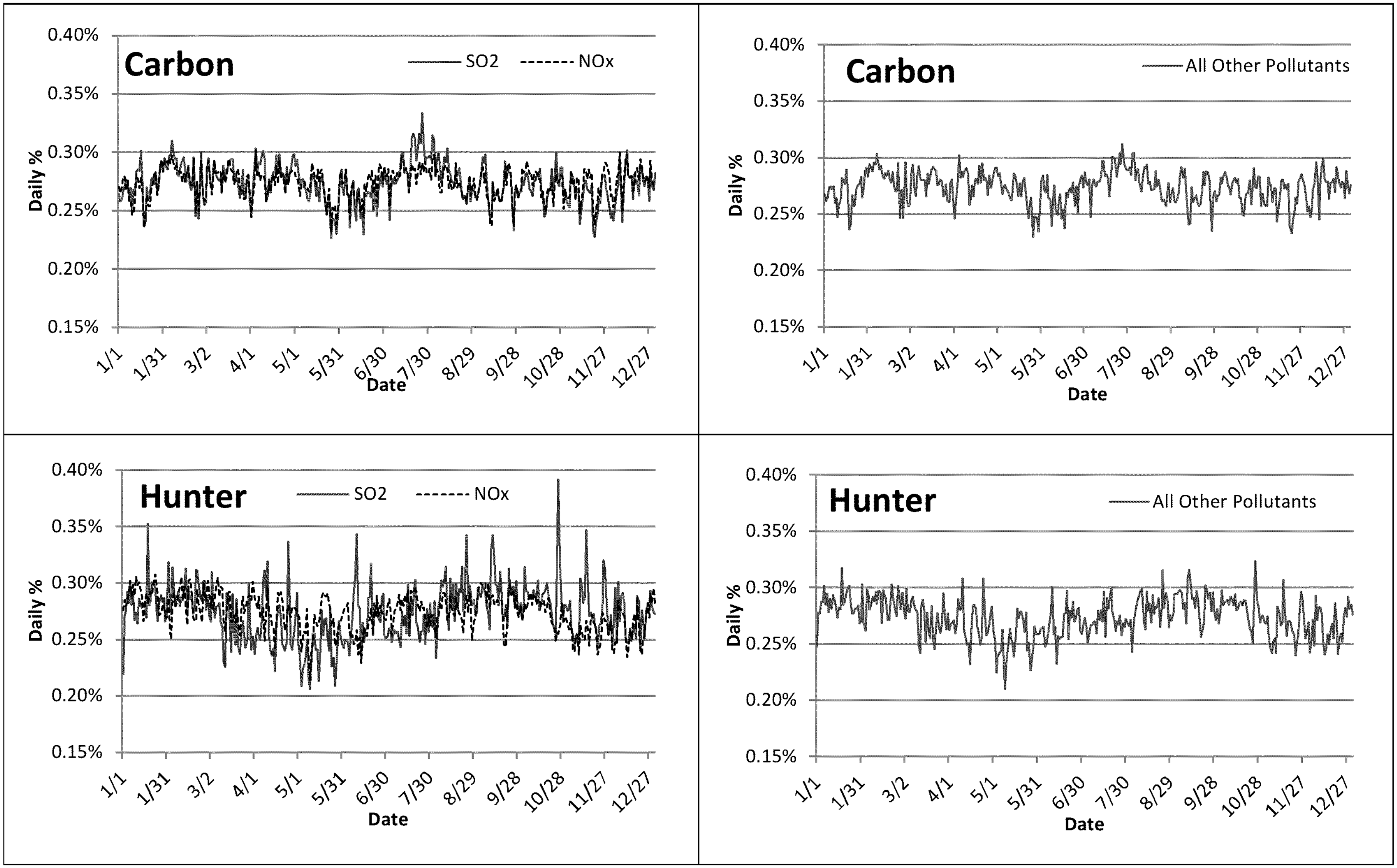
2.1.2 Baseline (2025) Modeling Scenario

The Baseline modeling scenario represents the emission values in the future year (2025) before any additional control technology (other than controls that were in operation during the PacifiCorp power plants baseline period of 2001-2003) was placed on any of the PacifiCorp power plants units to reduce emissions. This scenario will provide a baseline to compare the relative visibility improvement of the proposed emission controls by the USEPA FIP and PacifiCorp scenarios. In general, the Baseline modeling scenario is based on the dataset provided by the 2025 WAQS modeling platform. However, the PacifiCorp power plants emissions for this modeling scenario will be representative of the period 2001 to 2003 and they are identical to those described in the Typical Year (2011) scenario above. The temporal profile that will be used for PacifiCorp power plants emissions is described in Section 2.1.1. The annual emissions for the Baseline scenario are shown in **Table 2-3**.

Table 2-3 PacifiCorp Power Plants Emissions for the Baseline Modeling Scenario by Unit

Plant	Unit	NO_x tpy	SO_2 tpy	VOC tpy	CO tpy	PM_{10} tpy	$PM_{2.5}$ tpy	NH_3 Tpy
Carbon	1	1,312.4	2,285.7	7.4	61.6	119.9	86.9	1.3
	2	1,977.3	3,527.5	11.3	93.9	182.9	132.5	1.9
Hunter	1	6,379.7	2,535.1	45.1	375.4	733.0	537.0	8.4
	2	6,092.1	2,531.4	44.1	367.5	717.4	525.5	8.2
	3	6,530.2	1,204.0	32.6	271.8	530.6	388.7	6.1
Huntington	1	5,944.3	2,380.4	28.3	235.8	517.2	331.1	4.9
	2	5,816.5	12,308.0	56.5	470.7	1,032.6	661.0	9.7

A description of the regional emissions included in the modeling will be presented in Section 2.2. Like the Typical Year Scenario, all remaining EGUs emissions and temporal profiles will remain unchanged from the data provided by the 2025 WAQS modeling platform.


Carbon
SO2
NOx
Daily %
0.40%
0.35%
0.30%
0.25%
0.20%
0.15%
1/1 1/31 3/2 4/1 5/1 5/31 6/30 7/30 8/29 9/28 10/28 11/27 12/27
Date
Carbon
All Other Pollutants
Daily %
0.40%
0.35%
0.30%
0.25%
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1/1 1/31 3/2 4/1 5/1 5/31 6/30 7/30 8/29 9/28 10/28 11/27 12/27
Date
Hunter
SO2
NOx
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0.40%
0.35%
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Date

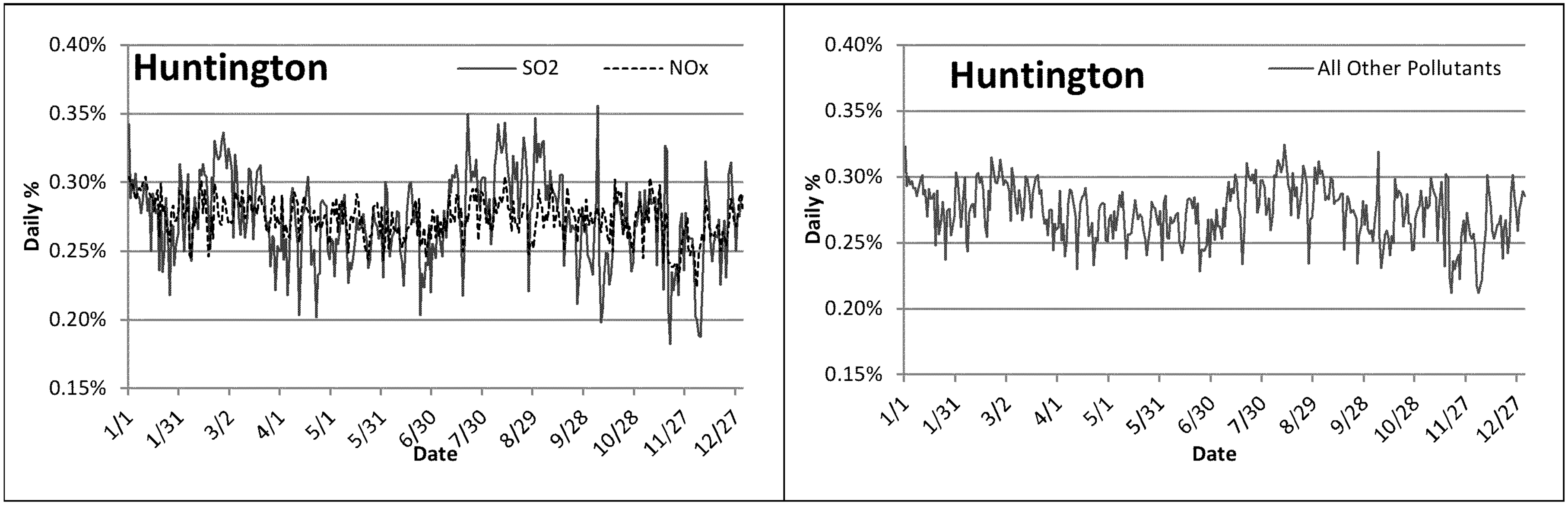

Figure 2-1 Emissions Temporal Profiles for NO_x and SO_2 (left) and all other Pollutants (right)

2.1.3 USEPA FIP (2025) Modeling Scenario

The USEPA FIP modeling scenario will be based on emission reductions that would take place as required by the FIP promulgated by the USEPA. The annual emissions for this modeling scenario are shown in **Table 2-4**. The values presented here represent the final USEPA determination for PacifiCorp Hunter Units 1 and 2 and Huntington Units 1 and 2 that includes the Low-NO_x Burners (LNB) with Separate Over-fire Air (SOFA) controls and Selective Catalytic Reduction (SCR) controls. NO_x emissions are reduced from the baseline using information presented in the FIP. The NOx emission reduction values for LNB with SOFA and SCR control option found in Tables 2 through 5 of the FIP for each unit were subtracted from the baseline emissions The resulting total controlled annual emission rate is 0.05 lb/MMBtu consistent with USEPA's BART analysis. All other pollutant emissions, except SO_2, also will be the same as the baseline. The NOx emissions from Carbon Units 1 and 2 and Hunter Unit 3 also will be the same as the baseline as these are non-BART sources according to the FIP (40 CFR Part 52 Vol. 81 No. 128).

Table 2-4 PacifiCorp Power Plants Emissions for USEPA FIP Modeling Scenario by Unit

Plant	Unit	NO_x tpy	SO_2 tpy	VOC tpy	CO tpy	PM_{10} tpy	$PM_{2.5}$ Tpy	NH_3 tpy
Carbon	1	1,312.4	2,285.7	7.4	61.6	119.9	86.9	1.3
	2	1,977.3	3,527.5	11.3	93.9	182.9	132.5	1.9
Hunter	1	879.7	1,238.6	45.1	375.4	733.0	537.0	8.4
	2	862.1	1,422.5	44.1	367.5	717.4	525.5	8.2
	3	6,530.2	1,252.1	32.6	271.8	530.6	388.7	6.1
Huntington	1	852.3	1,375.0	28.3	235.8	517.2	331.1	4.9
	2	793.5	1,178.0	56.5	470.7	1,032.6	661.0	9.7

2.1.4 PacifiCorp (2025) Modeling Scenario

The PacifiCorp scenario will be comprised of emission reductions due to the emission control strategy proposed by PacifiCorp Emission reductions for NOx and SO2 will be applied to the three Hunter units and the two Huntington units. Notice that this alternative considers decommissioning of the Carbon plant and thus the emissions related to this facility for all pollutants are zero. All other pollutant emissions at Hunter and Huntington will be the same as the baseline The annual emissions for this modeling scenario are shown in **Table 2-5**.

The temporal profile will be the same as the one described in Section 2.1.1 and like all other future year emissions scenarios the remaining EGUs emissions (except for PacifiCorp power plants) will remain unchanged from the 2025 WAQS modeling platform.

Table 2-5 PacifiCorp Power Plants Emissions for the PacifiCorp Modeling Scenario by Unit

Plant	Unit	NO_x tpy	SO_2 tpy	VOC tpy	CO tpy	PM_{10} tpy	$PM_{2.5}$ tpy	NH_3 tpy
Carbon	1	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0
Hunter	1	3,108.3	1,238.6	45.1	375.4	733	537	8.4
	2	3,040.8	1,422.5	44.1	367.5	717.4	525.5	8.2
	3	4,448.0	1,252.1	32.6	271.8	530.6	388.7	6.1
Huntington	1	3,432.5	1,375.0	28.3	235.8	517.2	331.1	4.9
	2	3,244.1	1,178.0	56.5	470.7	1,032.60	661	9.7

2.2 Regional Emissions Inventories and Modeling Domains

The regional photochemical model's skill to estimate future air quality and visibility impacts depends on its ability to simulate the complex interactions that occur between primary emissions sources (i.e., input emissions inventory) and meteorological conditions (i.e., output data from the WRF model). An important step is the gathering and processing of the emissions inventory for all sources within the modeling domain. The proposed emissions inventory development process is described in detail within the context of the proposed modeling domain.

2.2.1 Description of the Modeling Domains

A common strategy for regional photochemical modeling is to develop several nested modeling domains with finer grid resolution surrounding the areas of primary interest. In this case, the area of interest centers on PacifiCorp power plants as shown in **Figure 2-2**. The largest domain has a 36-km horizontal grid resolution (i.e., each grid cell is 36-km on a side), a smaller domain with a 12-km grid resolution, and the finest domain with a 4-km grid resolution centered on the project area and Class I areas of interest. The proposed modeling domains are described in further detail below and shown in **Figure 2-2**. For this study, 36-km and 12-km modeling results from WAQS will be used to provide pollutant concentrations entering the 4-km domain, referred to as lateral boundary conditions (BC) for the 4-km grid domain, and only the 4-km grid will be used to conduct the proposed modeling and corresponding visibility analysis.

2.2.1.1 Horizontal Modeling Domain

All CAMx modeling domains use the Regional Planning Organizations' (RPO) unified grid map projection, which has been used by both the Western Regional Air Partnership (WRAP) and USEPA. The RPO unified grid consists of a Lambert Conformal Conic (LCC) map projection with the parameters listed in **Table 2-6**. **Table 2-7** lists the size and dimensions of the 36-km, 12-km, and 4-km modeling domains proposed for the CAMx simulations. Notice that the coordinates for the 12-km and 4-km domains include the buffer cells required for performing two-way nested simulations. The WAQS performed 36-km and 12-km two-way nesting CAMx simulations for year 2011 and 2025 using the domains shown in **Figure 2-2**. The 12-km domain concentrations are used to establish the lateral boundary conditions of the 4-km domain when modeling both the base and future years for this analysis.

Table 2-6 RPO Unified Grid Definition

Parameter	Value
Projection	Lambert-Conformal Conic
Datum	World Geodetic System 1984
Standard Parallel 1	33° latitude N
Standard Parallel 2	45° latitude N
Central Meridian	97° longitude W
Latitude of Origin	40° latitude N

Table 2-7 CAMx Model Domain Dimensions

Domain	Number of Grid Cells	Coordinates of Southwestern Corner of Grid (km)
36-km	148 x 112	-2736, -2088
12-km	227 x 230	-2388, -1236
PacifiCorp 4-km	182 x 149	-1516, -412

2.2.1.2 Vertical Modeling Domain

The CAMx vertical domain structure depends on the definition of the WRF vertical layers structure with thinner (more) layers within the planetary boundary layer (PBL). The PBL is the lowest part of the atmosphere where the physical properties of the air are directly influenced by its contact with the ground surface. Within the PBL, the wind is affected by surface drag, influencing the wind speed, wind direction, and turbulence. The atmosphere above the PBL typically is referred to as the "free atmosphere" where the wind is usually non-turbulent, or only intermittently turbulent. Due to the different physical characteristics between the free atmosphere and the PBL, it is important to have the PBL well resolved in meteorological models. The vertical extent of the PBL changes throughout the day and season.

The altitudes above sea level are estimated according to standard atmosphere assumptions used in the WRF model.[1] The WAQS used WRF with 37 vertical layer interfaces from the surface up to 50 millibar (mb) (~19 km above ground level [AGL]). A layer averaging scheme is adopted for the CAMx simulations whereby multiple WRF layers are combined into one CAMx layer to reduce the air quality model computational time. The WAQS (IWDW 2016a) indicates that the lowest layers of WRF were mapped directly into CAMx with no layer collapsing the WRF layer 1 thickness, at 12m was found to be too shallow and may trap emissions in a too shallow layer resulting in overstated surface concentrations. Also the WAQS mentioned that several previous studies, like the 2008 Denver ozone SIP, have shown that collapsing layers that are higher aloft, results in thick vertical layers near the top of the modeling domain that contribute to the too rapid transport of high ozone concentrations of stratospheric ozone origin to the ground. The proposed layer structure is summarized in **Table 2-8**, which displays the approach for collapsing the WRF 37 vertical layers to 25 vertical layers in CAMx.

[1] Standard equations and assumptions include: surface pressure of 1,000 mb, model top at 100 mb, surface temperature of 275 degrees Kelvin (°K), and lapse rate of 50°K/ natural log-pressure (ln[p]).

Figure 2-2 CAMx Modeling Domains

Table 2-8 Vertical Layer Structure Proposed for WRF and CAMx Modeling Simulations

WRF Meteorological Model					CAMx Air Quality Model		
WRF Layer	Sigma	Pressure (mb)	Height (m)	Thickness (m)	CAMx Layer	Height (m)	Thickness (m)
37	0	50	19,260	2,055	25	19,260	3,904.9
36	0.027	75.65	17,205	1,850			
35	0.06	107	15,355	1,725	24	15,355.1	3,425.4
34	0.1	145	13,630	1,701			
33	0.15	192.5	11,930	1,389	23	11,929.7	2,569.6
32	0.2	240	10,541	1,181			
31	0.25	287.5	9,360	1,032	22	9,360.1	1,952.2
30	0.3	335	8,328	920			
29	0.35	382.5	7,408	832	21	7,407.9	1,591.8
28	0.4	430	6,576	760			
27	0.45	477.5	5,816	701	20	5,816.1	1,352.9
26	0.5	525	5,115	652			
25	0.55	572.5	4,463	609	19	4,463.3	609.2
24	0.6	620	3,854	461	18	3,854.1	460.7
23	0.64	658	3,393	440	17	3,393.4	439.6
22	0.68	696	2,954	421	16	2,953.7	420.6
21	0.72	734	2,533	403	15	2,533.1	403.3
20	0.76	772	2,130	388	14	2,129.7	387.6
19	0.8	810	1,742	373	13	1,742.2	373.1
18	0.84	848	1,369	271	12	1,369.1	271.1
17	0.87	876.5	1,098	177	11	1,098	176.8
16	0.89	895.5	921	174	10	921.2	173.8
15	0.91	914.5	747	171	9	747.5	170.9
14	0.93	933.5	577	84	8	576.6	168.1
13	0.94	943	492	84			
12	0.95	952.5	409	83	7	408.6	83
11	0.96	962	326	82	6	325.6	82.4
10	0.97	971.5	243	82	5	243.2	81.7
9	0.98	981	162	41	4	161.5	64.9
8	0.985	985.75	121	24			
7	0.988	988.6	97	24	3	96.6	40.4
6	0.991	991.45	72	16			
5	0.993	993.35	56	16	2	56.2	32.2
4	0.995	995.25	40	16			
3	0.997	997.15	24	12	1	24.1	24.1
2	0.9985	998.58	12	12			
1	1	1000	0	0			

2.2.2 Regional Emissions Inventory Data

This section provides a description of the regional emissions inventory to be used for both the 2011 typical year, and the three 2025 future year scenarios.

The typical year inventory produced for the 4-km simulation used emission inputs developed for the WAQS (IWDW 2016a and 2016b) as shown in **Table 2-9**. **Table 2-10** shows the proposed emissions inventory data sources for the future year modeling scenarios. Other than the PacifiCorp power plants emissions, all other emission datasets will remain constant among the three future year modeling scenarios. The emission inventories are modeled in this manner so any changes in model impacts can be attributed exclusively to differences in the PacifiCorp power plants emissions.

A complete emissions inventory for photochemical modeling includes point sources, area sources, non-road and on-road mobile sources, as well as ammonia emissions, windblown dust, biogenic emissions, and fire emissions. Ammonia emissions include agriculture, fertilizer, and livestock emission sources. Regional emissions sources that will be identical for all modeling scenarios include: windblown dust, biogenic, lightning, and fire emissions.

<u>Emissions Sources Held Constant for all Scenarios</u>

Windblown dust emissions can be a significant source of PM. For the WAQS study, the WRAP windblown dust model was run with 2011 meteorological data to provide an estimate of windblown coarse and fine soil dust emissions for each modeling domain.

The Model of Emissions of Gases and Aerosols for Nature (MEGAN), as developed by National Center for Atmospheric Research (NCAR), was used to estimate biogenic emissions for the WAQS study. The most current version of MEGAN was used (version 2.1). MEGAN requires several types of input data, including: vegetation input data (Leaf area indices); emissions factors; classification of a grid cell's plant functional types (PFT); and wilting point for each PFT. MEGAN also requires as input hourly, gridded temperature and solar radiation data to estimate biogenic emissions. These data were derived from the WAQS and WRF model output.

Important emission sources of PM and precursors of ozone that will be included in the fire emissions inventory include wild fires, prescribed burning and agricultural burning. The WAQS used the 2011 fire emissions inventory were generated by the Particulate Matter Deterministic and Empirical Tagging and Assessment of Impacts on Levels (PMDETAIL) study.

2.2.2.1 2011 Typical year Emissions Inventory

As stated previously, the typical year modeling used the WAQS emissions inventory with no additional modifications, other than those for PacifiCorp power plants described above. The typical year emissions inventory processed for WAQS is shown in **Table 2-9**. The majority of the emissions modeling is based on version 6.2 of the 2011 NEI from the USEPA with additional enhancements as described in the WAQS Modeling Protocol (IWDW 2016a and 2016b)

Table 2-9 Typical Year 2011 Emissions Inventory Data Sources from WAQS

Component	Configuration	Details
PacifiCorp power plants: Carbon, Hunter, and Huntington	See Section 2.1.1	See Section 2.1.1
Oil and Gas Emissions	WAQS 2011p1 and 2011 NEIv6	Used the WAQS 2011 Phase I inventory and the NEI 2011v6 inventory for all areas outside of the WAQS inventory coverage area
Non-point Source	2011 NEIv6	County-level emissions for sources that individually are too small in magnitude or too numerous to inventory as individual point sources.
On-road Mobile	2011 NEIv6 via MOVES20110414a	County specific emissions run for monthly weekday and weekend days. California and Texas MOVES estimates were normalized to emission values provided by these states
Point Sources	2011 Continuous Emissions Monitoring (CEM) and 2011 NEIv6	Use 2011 day-specific hourly measured CEM from the CAMD for SO_2 and NO_X emissions for CEM sources, 2011 NEIv6 for other pollutants and non-CEM sources
Off-road Mobile Sources	2011 NEIv6	Based on USEPA NONROAD2008a model
Biogenic Sources	MEGAN	Enhanced version of MEGAN Version 2.1
Wind Blown Dust Emissions	WRAP Wind Blown Dust (WBD)	WRAP WBD Model with 2011 WRF meteorology
Fires	PMDETAIL	Hourly agricultural, prescribed, and wildfire sources with pre-computed plume parameters and speciated PM
Mexico Sources	MNEI2012	Mexican NEI 2012
Canada Sources	NPRI2006	Canadian 2006 National Pollutant Release Inventory
Lightning NO_X	2011 WRF	Gridded hourly nitric oxide (NO) emissions tied to WRF convective rainfall
Sea salt	2011 WRF	Surf zone and open ocean PM emissions tied to WRF

The USEPA NEI database contains information relative to sources that emit criteria air pollutants and their precursors. The database includes estimates of annual air pollutant emissions from point, nonpoint, and mobile sources in the 50 states, the District of Columbia, Puerto Rico, and the Virgin Islands. The USEPA collects information about sources and releases an updated version of the NEI database every 3 years.

The USEPA compiles the NEI database from these primary sources:

- Emissions inventories compiled by state and local environmental agencies;
- Databases related to the USEPA Maximum Achievable Control Technology programs to reduce emissions of hazardous air pollutants;
- Toxic Release Inventory data;
- Emission Tracking System CEM data and Department of Energy fuel use data (for electric generating units);
- Federal Highway Administration estimate of vehicle miles traveled (VMT) and emissions factors from the USEPA motor vehicle emission simulator (MOVES) computer model (for on-road sources);

- NONROAD computer model (for nonroad sources); and
- Previous emissions inventories (if states do not submit current data).

2.2.2.2 Future Year Modeling Scenarios

The future year emissions inventory will be based on the future year projected inventory from the WAQS as outlined in **Table 2-10**. The main data source will be the 2025 Projections from the 20011 NEIv6 inventory. The 2011 emissions of windblown dust, biogenic, lightning, sea salt, and fire sources categories will be used in the future year modeling scenarios, which is consistent with the 2025 Projections from the 2011 NEIv6 development approach whereby the non-anthropogenic emissions do not change between the typical year and future year modeling scenarios.

Table 2-10 Future Year Modeling Scenarios Emissions Inventory Data Sources

Major Source Type	Location	Projection Method
Point Sources[1]	PacifiCorp power plants	See Sections 2.1.2 to 2.1.4
	Whole Domain	2025 Projections from the 2011NEI v6
Area Sources[1]	Whole Domain	2025 Projections from the 2011 NEI v6
Oil and Gas	Whole Domain	2025 Projections from the 2011 NEI v6
On-road Mobile sources	Whole Domain	2025 Projected MOVES lookup tables from MOVES2010b
Off-road Mobile Sources	Whole Domain	2025 Projections from the 2011 NEI v6 inventory
Ammonia Emissions	Whole Domain	2025 Projections from the 2011 NEI v6 inventory
Biogenic	Whole Domain	Hold typical year 2011 emissions constant.
Wind Blown Dust Emissions	Whole Domain	Hold typical year 2011 emissions constant.
Fires	Whole Domain	Hold typical year 2011 emissions constant.
Non-US sources	Outside US	Hold typical year 2011 emissions constant.
Lightning NO_X	Whole Domain	Hold typical year 2011 emissions constant.
Sea salt	Whole Domain	Hold typical year 2011 emissions constant.

[1] A non-mineral source (point or area) indicates any source that is not included in coal mining, conventional oil and gas, coalbed natural gas (CBNG), or other mining source categories.

3.0 Photochemical Model Configuration

The proposed photochemical modeling analysis will quantify the potential visibility impacts expected as a result of the different control strategies on the PacifiCorp power plants emissions. This chapter provides a detailed description of the CAMx configuration that will be used for the assessment

3.1 Approach Overview

The CAMx modeling system includes both meteorological (WRF model) and emissions processing models (SMOKE), in addition to the photochemical grid model. This chapter provides a detailed approach to the proposed setup and configuration of the CAMx modeling system for this analysis. The CAMx modeling system will be run for the typical year and three future year modeling analyses as described in Chapters 1.0 and 2.0.

The 2011 Three-State Air Quality Study (WAQS) WRF modeling results have been used to provide the meteorological inputs to the WAQS and Western Air Quality Study (WAQS) (IWDW 2016a and 2016b). These gridded meteorological data will be used in all CAMx modeling simulations. The emissions inventory will be processed in a similar fashion for all modeling cases; however, the PacifiCorp power plants input emissions data will differ in each simulation. The CAMx model configurations and 4-km domain boundary conditions will be identical in all cases.

The modeling methodology will follow USEPA's established guidance on the use of regional PGM modeling procedures for demonstrating air quality goals for PM, and regional haze (USEPA 2007, 2014). Finally, CAMx modeling results for future years will be post-processed to derive model estimates of light extinction coefficients for inter-comparison among all the scenarios considered in this analysis.

3.2 WRF Model

Photochemical grid models require meteorological data to simulate air quality conditions. A prognostic meteorology model such as the WRF model (Skamarock et al. 2008; NCAR 2009) is generally used to provide gridded meteorological data at the same grid resolutions and spatial extent of the PGM computational domains.

This study relies on the WRF meteorological modeling conducted for the 2011 WAQS platform. The WRF modeling results for the 2011 annual period were evaluated against surface meteorological observations of wind speed, wind direction, temperature and humidity. The complete details of both the WRF configuration and the results of the model performance evaluation can be found in the WRF Final Report (UNC and Ramboll Environ 2015). The WRF model output will be processed as needed with the WRFCAMx processor to generate the 36-km, 12-km, and 4-km meteorological inputs for all the CAMx modeling simulations in this study.

3.2.1 Meteorological Inputs to Emissions and Air Quality Models

Air quality models require certain meteorological input data including wind fields, estimates of turbulent eddy dispersion, humidity, temperature, clouds, and solar radiation. Additionally, the WRF meteorological parameters are used to solve the transport and chemical reaction equations in the air quality model.

Since the WAQS performed CAMx simulations for the 36-km Continental U.S. (CONUS), 12-km western U.S. (WESTUS) domain and 4-km domain covering the states of Colorado, Wyoming, and Utah and neighboring areas, it is expected that the study proposed here will not require processing of the WRF meteorology with WRFCAMX for those domains. However, WRFCAMX might have to be used to process the WRF meteorology for the 4-km domain described in Chapter 2 This will be assessed once the WAQS data has been provided

3.3 Emissions Processing for Input into CAMx using SMOKE

The SMOKE emissions processing system was developed by MCNC (Coats 1995; Houyoux and Vukovich 1999) and has continued to be developed and maintained through the Center for Environmental Modeling for Policy Development (CEMPD) of the University of North Carolina (UNC) at Chapel Hill Institute for the Environment (IE). SMOKE is an emissions processing system that converts emissions inventory data into the formatted emissions files required by an air quality simulation model. SMOKE supports area, fire, and point source emissions processing and also has the ability to run emissions models that require meteorological data, such as biogenic models or mobile source models. SMOKE has been available since 1996 and has been used for emissions processing in numerous regional air quality modeling applications, such as WRAP visibility studies and O_3 modeling for SIPs, and it is the preferred emissions processing system by USEPA. SMOKE contains a number of major features that make it a useful component of the CAMx modeling system and it supports a variety of input formats from other emissions processing systems and models.

SMOKE originally was designed to allow emissions data processing methods to utilize emergent high-performance-computing as it is applied to sparse-matrix algorithms. The sparse matrix approach utilized throughout SMOKE permits both rapid and flexible processing of emissions data. The processing is rapid because SMOKE utilizes a series of matrix calculations instead of the less efficient algorithms used in previous systems. The processing is flexible because the processing steps of temporal projection, controls, chemical speciation, temporal allocation, and spatial allocation have been separated into independent operations wherever possible. The results from these steps are merged together at a final stage of processing.

3.3.1 SMOKE Processing

SMOKE will be configured to generate emissions files in a format that is compatible with PGMs. There are several different types of emissions processed by SMOKE, including point, area, non-road, on road, fire, and biogenic emissions. These source types can be processed separately in order to prepare emission inventories for modeling with a PGM. SMOKE consists of several processing routines:

- Spatial Allocation. The spatial resolution of the emissions must match the CAMx grid cells for each domain. Initial area, non-road mobile, and on-road mobile emission inventories are spatially resolved at the county level, an area that is much too coarse for the CAMx grid resolution. Therefore, county-level emissions are allocated to the grid cells within each county based on spatial surrogates (e.g., population, land use categories, and economic activity).
- Chemical Speciation. Emission inventories do not routinely include estimates of each chemical species, rather total VOC, total PM, and NO_X are reported. Emissions of total VOC are converted to estimates of number of carbon bond types required for use of the Carbon Bond version 6 release 2 (CB6r2) (Yarwood et al. 2010) chemical mechanism in CAMx. Total unspeciated NO_X emissions are allocated to NO and nitrogen dioxide (NO_2) components (and nitrous acid (HONO) in some emissions sectors). PM is allocated to coarse PM, nitrate, sulfate, organic carbon, elemental carbon, and other fine particulates. Speciation profiles for each emissions source classification code (SCC) will be consistent with the profiles from the WAQS

- Temporal Allocation. Emissions are provided for different averaging periods for each source type. Those source types with annual or short-term emission rates will be adjusted to seasonal or monthly profiles accounting for day-of-week and hour-of-day differences. Area sources, including non-road mobile and dust emissions are allocated by monthly, daily, and hourly profiles provided by the USEPA. Biogenic and on-road mobile emissions will be modeled using hourly meteorological data. Point sources, including CEM data and fire emissions, will be modeled with available day-specific, or hour specific emissions and meteorology.
- Elevated Sources. For point sources with plume rise of greater than 20m, those point sources will be treated as elevated sources. With the exception of PacifiCorp power plants, no Plume-in-Grid (PiG) treatment will be applied to any other elevated point sources.
- Quality Assurance. SMOKE includes quality assurance (QA) and reporting features to keep track of the adjustments at each processing stage and ensure that data integrity is not compromised. The QA tools from SMOKE will be used to provide summary plots and tables of emissions for inclusion in the final report.

All ancillary files used for SMOKE processing will be obtained from the WAQS, with the exception of the PacifiCorp power plants-specific emissions data that has already been disclosed in Chapter 2.

In general, all emissions will be processed by SMOKE in a manner consistent with the WAQS. As stated in Chapter 2.0, the typical year emission inventories for all domains will be directly taken from the WAQS, which was processed using the SMOKE model. Since the 4-km domain proposed in this study is a subdomain of the original 4-km WAQS, AECOM will extract the final emissions from the 4-km WAQS domain. AECOM will re-process the WAQS emissions combined with the modified PacifiCorp power plant emissions through SMOKE in a manner consistent with the WAQS.

3.3.2 Emissions Inventory Quality Assurance

In addition to the CAMx-ready input files generated by SMOKE for each hour of each modeled day, a number of QA files will be prepared and used to check for errors in the emissions inputs.

Importing the model-ready emissions into the Package for Analysis and Visualization of Environmental data (PAVE) or the NCAR Command Language (NCL) for visualization, and looking at both the spatial and temporal distribution of the emissions, provides insight into the quality and accuracy of the emissions inputs. The QA procedures for the processed emissions data will include the following:

- Visualize the model-ready emissions with the scale of the plots set to a very low value. This shows whether there are areas omitted from the raw inventory or if emissions sources are erroneously located in water cells.
- Spot-check the holiday emissions files to confirm that they are temporally allocated.
- Spot check vertical allocation of point sources using PAVE or NCL.
- State inventory summaries prepared prior to the emissions processing will be compared against SMOKE output report totals generated after each major step of the emissions generation process.

To check the chemical speciation of the emissions to CB6r2 terms and the vertical allocation of the emissions, automatically generated reports will be compared with SMOKE reports to target specific areas of the processing. For speciation, the inventory state totals will be compared to the same state totals with the speciation matrix applied.

The quantitative QA review may reveal deficiencies in the input data or the model setup. It may become necessary to tailor these procedures to track down the source of major data errors. Special care will be given to the PacifiCorp power plants emissions for the various scenarios. In particular, SMOKE reports will be generated to review that the correct elevated source have been selected as elevated and plume in-grid has been included.

The SMOKE QA tools will be used to review the quality of the emissions files that will be provided as input to CAMx. The final report will contain selected summary tables of emissions by source type and for the PacifiCorp power plants emissions for the various scenarios in the 4km CAMx modeling domain.

3.4 CAMx Model Inputs

In addition to emissions rates and meteorological fields, CAMx requires additional input files that configure each simulation, define the chemical mechanism, describe the photochemical conditions, describe surface characteristics, and set initial conditions (IC) and boundary conditions (BC) over the entire modeling domain. CAMx modeling inputs include:

- CAMx-ready three-dimensional (3-D) hourly meteorological fields generated by WRFCAMx, the processor used to prepare input meteorology files from the WRF output;
- Two-dimensional low-level (surface layer) emissions and elevated point source emissions generated by the SMOKE emissions processor;
- Initial conditions (IC) and boundary conditions (BC) generated by the CAMx IC/BC processors. The 36-km domain lateral boundaries concentrations in the WAQS are based on the Model for Ozone and Related chemical Tracers (MOZART) global chemistry model;
- Albedo/Haze/O_3 Column input file;
- Photolysis rates look up table; and
- Land use and topography data.

Table 3-1 summarizes the main CAMx configurations that will be used for this study. For future year simulations, in case the three-dimensional 12-km 2025 future year CAMx outputs are not available from the IWDW, a two-way nesting simulation will be performed for the 36-km and 12-km domains with subsequent one-way nesting simulations for the 4-km. The configuration of CAMx will use the vertical layers as presented in **Table 2-8**. The Piecewise Parabolic Method (PPM) advection solver will be used along with the spatially varying horizontal diffusion approach. Vertical diffusion in CAMx will be modeled by K-theory. The meteorological fields from WRF will be processed using the WRFCAMx processor as needed.

Table 3-1 CAMx Air Quality Model Configurations

Science Options	Configuration	Details
Model Version	CAMx V6.10	
Vertical Grid Mesh	25 vertical layers collapsed from WRF's 37 vertical layers structure	Layer 1 thickness ~24- m. Model top at ~19-km (AGL)
Grid Interaction	Two-way nesting for 36- and 12-km domains. One-way nesting for the 4-km domain.	
Plume-in-Grid (PiG)	Invoke PiG for all three PacifiCorp power plants	Subgrid-scale plume chemistry and dynamics module will be used for PacifiCorp power plants
Initial Conditions	10 day spin-up for 36-km and 12-km. 3 day spin-up for 4-km domains	December 21-31, 2010 for 36-km and12-km domains. 4-km IC derived from 12-km modeling results

Table 3-1 CAMx Air Quality Model Configurations

Science Options	Configuration	Details
Boundary Conditions	36-km from MOZART global chemistry model	4-km boundary conditions derived from 12-km modeling results
Chemistry		
Gas Phase Chemistry	CB6r2	Carbon Bond 6 version 2
Aerosol Chemistry	inorganic aerosol thermodynamics/partitioning model (ISORROPIA) equilibrium	
Cloud Chemistry	Regional Acid Deposition Model (RADM)-type aqueous chemistry	
Meteorological Processor	WRFCAMx	Compatible with CAMx v6.10
Horizontal Transport	K-theory with grid size dependent coefficient of horizontal eddy diffusion	
Vertical Transport	K-theory (CMAQ-like in WRFCAMx)	Lower limit of vertical eddy diffusivity = 0.1 m^2/s or 2.0 m^2/s ; Land use dependent
Deposition Scheme	Zhang dry deposition and CAMx-specific formulation for wet deposition	rain/snow/graupel/virga
Numerics		
Gas Phase Chemistry Solver	Euler Backward Iternative (EBI) Fast Solver	
Horizontal Advection Scheme	Piecewise Parabolic Method (PPM) scheme	
Integration Time Step	Wind speed dependent	~0.1-1 min (4-km), 1-5 min (12-km), 5-15 min (36-km)

As described in previous chapters, meteorological inputs for CAMx are generated using the WRFCAMx processor and the emissions inputs will be generated with the SMOKE model. In addition to the meteorology and emissions inputs, the CAMx model requires ancillary data, including initial and boundary concentrations for all chemical species, and O_3 column data for calculating photolysis rates. The sources of these ancillary data are described in detail below.

3.4.1 Initial and Boundary Concentration Data

Additional input data required for photochemical grid model simulations include the three-dimensional concentration fields of chemical species to initialize the model, and concentrations of chemical species at the lateral boundaries of the 36-km grid.

Typically, initial concentration values are created by performing a model spin-up simulation. The CAMx spin-up simulation will be initialized using initial concentrations meant to represent clean atmospheric conditions and will be operated using emissions and meteorological data for a pre-determined period of time. The three-dimensional initial concentrations generated from a spin-up simulation are more representative of actual ambient concentrations than are default initial values. The results of the CAMx spin-up simulation will be used to initialize the CAMx modeling simulations, thereby eliminating the influence of the default initial concentration values

If the 36/12-km domains three-dimensional modeling output is not available, these simulations will be performed with a 10-day of spin-up period, whereas for the 4-km model domain, in which the initial and boundary conditions will be derived from the coarser 12-km three-dimensional concentrations fields, a 3-

day of spin-up period will be used To reduce the time required for annual model simulations, the simulations will be performed in separate runs of 3 months each, with an additional spin-up period for each 3-month period. For each subsequent quarter, the final days of the preceding quarter will be used to spin up the model. The additional spin up period eliminates effects of initial conditions.

The boundary concentration data for the 36-km domain in the CAMx modeling simulations are derived from average concentration fields from a 2011 MOZART global simulation model output. The MOZART horizontal and vertical coordinate systems are interpolated to the CAMx Lambert Conformal Conic Projection. Also the MOZART chemical species have been mapped to the CB6r2 chemical mechanism used by CAMx. It should be noted that because adverse model performance impacts were observed from excessive dust and sea salt particle concentrations entering the modeling domains from the outer boundary using MOZART in the WAQS 2011 base year simulation (IWDW 2016a and 2016b), both the dust and sea salt concentration were ultimately zeroed out in the MOZART boundary conditions.

3.4.2 Photolysis Rates

Several chemical reactions in the atmosphere are initiated by the photodissociation of various trace gases. Accurate estimates of these photodissociation rates should be made to represent the complex chemical transformations in the atmosphere. The CAMx model AHOMAP processor prepares albedo/haze/O_3 column input files for CAMx. The CAMx total ultraviolet (TUV) preprocessor then calculates a table of clear-sky photolysis rates for each grid cell for a specific date. TUV accounts for environmental parameters that influence photolysis rates including solar zenith angle, altitude above the ground, surface ultraviolet albedo, aerosols (haze), and stratospheric O_3 column. Photolysis rates are derived for each grid cell assuming clear sky conditions as a function of five parameters including solar zenith angle, altitude, total O_3 column, surface reflectivity, and atmospheric turbidity. The CAMx version of TUV is modified to output information in a format directly compatible with CAMx for the CB6r2 chemical mechanism.

The surface ultraviolet albedo is calculated based on the gridded land use data using land use-specific ultraviolet (UV) albedo values. The albedo varies spatially according to the land cover distribution, but typically does not vary with time.

3.5 PM Source Apportionment Technique

The CAMx Particulate Source Apportionment Technology (PSAT) (Yarwood et al. 2004) will be used to obtain an estimate of the contributions to PM and the corresponding visibility impairment in the future year modeling analyses from each of the PacifiCorp power plants. PSAT provides source-category apportionment of modeled PM by individual species or by several species aggregation methods. PSAT has been developed to retain the advantage of using a grid model to describe the chemistry of secondary PM formation and also to provide an estimate of the contribution from individual sources, or groups of sources, to the total modeled concentration. PSAT will be invoked to explicitly tag and track the contributions to PM from each PacifiCorp Power Plant within the modeling domain. The PSAT configuration in CAMx will be setup to include the following tracers: Sulfur (Sulfate tracers), nitrogen (nitrate and ammonium tracers) and primary particulate matter (elemental carbon, organic aerosol, crustal PM tracers). Due to the relatively small modeled concentrations of secondary organic aerosol (SOA) from the power plants emissions, and the relatively large runtime penalty of the SOA PSAT mechanism, SOA will not be selected to be part of the PSAT tracers for this study.

3.6 Model Performance Evaluation

This section provides a summary of the Model Performance Evaluations (MPEs) that the IWDW performed on both the meteorological and the photochemical grid models in order to understand and evaluate the biases, errors and limitations that always need to be considered in any subsequent analysis that relies on this modeling platform.

3.6.1 Meteorological Model Performance Evaluation

Both qualitative and quantitative MPEs were performed to evaluate the WRF model for the 2011 base year annual simulation. The goal of this type of evaluation was to determine whether the meteorological fields are sufficiently accurate for the air quality model to properly characterize the transport, chemistry, and removal processes. Also to provide a reasonable meteorological characterization, the WRF model should reproduce the large scale patterns; mesoscale and regional wind, temperature, PBL height, humidity, and cloud/precipitation patterns; mesoscale circulations such as sea breezes and mountain/drainage circulations; and diurnal cycles in PBL depth, temperature, and humidity. The details of the model performance can be found in 3SAQS Weather Research Forecast 2011 Meteorological Model Application/Evaluation Report (UNC and Ramboll Environ 2015). While the WRF model performance statistics showed good overall performance benchmarks for surface winds, temperature, and mixing ratios across the 4km WAQS and 12-km domains on a domain-wide and state-by-state basis, some notable limitation/shortcomings are relevant:

- WRF exhibited some difficulties simulating the nighttime temperature inversion in regions with mountainous terrain. It was found that warm bias at night in Utah during the winter months and cool bias during nighttime hours in other areas.
- WRF consistently under-predicts wind speed by about 0.5 m/s throughout the entire year across much of the modeling domains.
- A distinct seasonal pattern in mixing ratio bias was observed, in which WRF generally over predicted the mixing ratio in the cooler months and under-predicted during the warmer months across much of the modeling domain.

In general, WRF was able to reproduce fairly well the spatial distribution and magnitudes of the Parameter-elevation Relationships on Independent Slopes Model (PRISM) monthly precipitation analysis fields during all seasons except summer when WRF monthly precipitations showed greater differences from the PRISM analysis fields during monsoon conditions.

3.6.2 Air Quality Model Performance Evaluation

As stated in Chapter 1, the WAQS performed the photochemical grid modeling for the year 2011 using CAMx v6.10. WAQS also conducted a model performance evaluation (MPE) for the WAQS 2011 base year simulation version B (Adelman et al 2016) for a wide range of air pollutants and air quality related values, including ozone, $PM_{2.5}$, wet deposition, and light extinction. For the purpose of evaluating visibility impacts we summarize here the MPE results for $PM_{2.5}$ as well as the light extinction MPE to disclose any limitations of the model for this study.

The analysis showed that on an annual and domain-wide basis, total $PM_{2.5}$ and all its components except NO_3, were within both performance criteria for bias (≤±60%) and error (≤±75%). CAMx showed significant under-prediction in NO_3 when comparing ambient monitoring data. The WAQS MPE indicates that the nitrate underestimates in all seasons could be in part the result of overestimation of the deposition of NO_3, but a more likely source would be underestimation of urban NO_x emissions. In particular for the state of Utah, the WAQS MPE indicates that the model shows good agreement for total $PM_{2.5}$ mass, the compositional differences relative to IMPROVE observations state-wide are greatest in Utah due to underestimates in OC, NH_4 and NO_3, and overestimates in other PM and SO_4.: ,.

In general, when comparing reconstructed light extinction to the IMPROVE estimates, CAMx slightly under-estimates total light extinction not only across 4-km domain but also in Colorado, Wyoming, and Utah, in spite some differences exist between species and in other parts of the modeling domain. The CAMx annual average light extinction showed that the model underestimates the SO_4 contribution to light extinction, which is offset by over-estimates of the sea salt contribution at many of the IMPROVE sites. CAMx also under-estimated the contribution of soil to light extinction, which is likely due to the over correction of the boundary condition dust in simulation Base 11b.

4.0 Visibility Impacts Assessment

The potential air quality impacts from PacifiCorp's power plants will be estimated using the air quality modeling results. The modeling results will be post processed and intercompared for the different future modeling scenarios considered. Results will be reported as described in the following sections.

4.1 Assessment Areas

The assessment areas to be analyzed for visibility impacts will include the following Class I areas:

1. Grand Canyon National Park (NP)
2. Arches NP
3. Black Canyon of the Gunnison NP
4. Bryce Canyon NP
5. Canyonlands NP
6. Capitol Reef NP
7. Mesa Verde NP
8. Zion NP
9. Flat Tops Wilderness Area (WA)
10. Mount Zirkel WA
11. Maroon Bells-Snowmass WA
12. West Elk WA
13. La Garita WA
14. Weminuche WA
15. San Pedro Parks WA

Visibility impacts estimates will be reported for all of these Class I areas following the procedures detailed in subsequent sections. **Figure 4-1** shows the locations of the sensitive areas in relation to the modeling domain and PacifiCorp power plants.

4.2 Methodology

This section describes the methodology that will be used to derive the visibility impacts and how that information is used to compare the USEPA FIP and PacifiCorp alternative modeling scenarios. The CAMx configuration described in Chapter 3.0 will be used to run the modeling scenarios described in Chapter 2.0. The CAMx model will produce hourly results of both cumulative air quality concentrations and the PacifiCorp's power plants contributions to PM species at every grid cell. The ultimate objective is to isolate the changes in visibility as a result of emissions controls applied to PacifiCorp's power plants, the proposed closing of the Carbon power plant and potentially other non-control equipment emissions reductions. To assess compliance with Regional Haze Rule requirements, visibility changes will be assessed during the 20 percent best visibility days and during the 20 percent worst visibility days at each potentially affected, federally regulated Class I area indicated in Section 4.1.

Future visibility conditions at the Class I areas listed above will be estimated for all three future year modeling scenarios. To convert model concentrations into visibility conditions and account for quantifiable model bias, this project will rely on either the USEPA's Modeled Attainment Test Software

(MATS) tool version 2.6.1 (Abt Associates, Inc. 2014) or the most recent version of the Software for Model Attainment Test – Community Edition (SMAT-CE) (USEPA 2015) available at the time there are modeling outputs available from each scenario in this project. SMAT-CE represents an updated version of the modeled attainment for visibility software but the current version (1.01) is still not the final version available for public release. We will refer in the rest of this document to SMAT-CE as the tool to be used for the analysis but a final determination will be agreed in conjunction with USEPA before proceeding with the visibility assessment. More information about the SMAT-CE tool, its purpose, and how it is configured for this analysis is provided in the section below. The main objective of using SMAT-CE is to provide visibility estimates that mitigate the potential modeling biases. Once visibility estimates are calculated in SMAT-CE for each model scenario, the process will be repeated modifying the inputs to SMAT-CE in order to isolate the visibility impacts of PacifiCorp's power plants for each model scenario. As a final step, results from the PacifiCorp Alternative scenario will be compared to the Baseline and USEPA FIP scenarios to determine which has the least impact on visibility.

Figure 4-1 Class I Areas in the 4km CAMx Domain

(insert GIS figure)

The following steps will be performed in order to estimate visibility impacts[2]:

1. Apply SMAT-CE. Repeat this process three times, once for each of the three future year modeling scenarios relative to the Typical Year. This step provides the future 'cumulative' visibility conditions from all the regional sources, including PacifiCorp's power plants, for each future year model scenario.
2. Subtract PacifiCorp's power plants concentrations estimated with PSAT from the cumulative air quality concentrations. Repeat this process three times, once for each of the three future year modeling scenarios and the associated PacifiCorp's power plants contributions to those scenarios. This step provides estimates of cumulative air quality concentrations, excluding PacifiCorp's power plants, for each of the three future year modeling scenarios.
3. Apply SMAT-CE using the regional concentrations derived in Step 2 which exclude PacifiCorp's power plants air quality contributions. Repeat this process three times, once for each of the three future year modeling scenarios. This step provides the future 'cumulative' visibility conditions from all regional sources, excluding PacifiCorp's power plants, for each future year model scenario.
4. Subtract the future cumulative visibility estimates without PacifiCorp's power plants (derived in Step 3) from the future cumulative visibility estimates with PacifiCorp's power plants (derived in Step 1). Repeat this process three times, once for each of the three future year modeling scenarios. This step provides estimates of PacifiCorp's power plants contributions to visibility impacts for each modeling scenario.
5. Subtract the results of Step 4 for the Baseline scenario from the PacifiCorp scenario. This step provides the predicted visibility benefits from the PacifiCorp scenario relative to the 2025 Baseline.
6. Subtract the results of Step 4 for the USEPA FIP scenario from the PacifiCorp scenario. This step provides the predicted visibility benefits from the PacifiCorp scenario relative to USEPA FIP.

The approach described above relies on the PacifiCorp's power plants contribution derived using CAMx PSAT (described in Section 3.5). Results from the steps above are evaluated in a manner similar to that presented in the Technical Support documents for the Cross-State Air Pollution Rule (CSAPR) (USEPA 2011) and the Clean Air Interstate Rule (CAIR) (USEPA 2005a). The visibility improvements from two emissions strategies can be compared using a proposed "better-than-USEPA FIP" assessment that consists of a two pronged test. Under the first prong, visibility must not decline at any Class I area for the PacifiCorp scenario when compared to future baseline visibility conditions (i.e., the Baseline scenario). This prong is satisfied if the difference between the PacifiCorp scenario and the Baseline scenario is negative or zero at each Class I area. Under the second prong, the average visibility over all Class I areas must be better under the PacifiCorp scenario than under the USEPA FIP scenario. For the second prong, the average visibility improvement over all affected Class I areas must be negative or zero. It is acceptable if some Class I areas show greater improvement under the USEPA FIP scenario, as long as the average improvement is larger under the PacifiCorp scenario. The objective of these tests is to evaluate the visibility impacts under the PacifiCorp scenario and determine if the predicted visibility will be better than the USEPA FIP during both the 20 percent best and worst days for all Class I areas

[2] Steps 1 through 4 are necessary to isolate the visibility contribution from PacifiCorp's power plants because MATS requires cumulative air quality concentrations, rather than single source concentrations that will be obtained using PSAT.

4.1. The SMAT-CE Tool, Visibility Calculation Method, and SMAT-CE Configuration Options

For this analysis, visibility impacts will be assessed using SMAT-CE version 1.01 (USEPA 2015). SMAT-CE provides model-adjusted impacts that are consistent with USEPA's "Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of the Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze" (USEPA 2014). All models are affected by biases, i.e., model results are a simplification of natural phenomena and, as such, model results tend to over or under estimate true impacts. The use of SMAT-CE aids in mitigating model bias by pairing model estimates with actual measured conditions.

SMAT-CE calculates baseline and future-year visibility levels for both the 20 percent best and 20 percent worst days for each Class I Area. To do this, SMAT-CE adjusts the modeled air quality concentrations based on measured air quality concentrations to account for possible model bias utilizing the relative response factor approach described below. Within SMAT-CE, model-predicted concentrations of chemical compounds that scatter or absorb light are converted to estimates of light extinction using the IMPROVE equation (Hand and Malm 2006). The IMPROVE equation reflects empirical relationships derived between measured mass of PM components and measurements of light extinction at IMPROVE monitoring sites in Class I areas. The IMPROVE equation calculates light extinction as a function of relative humidity for large and small particulate matter. As a final step in SMAT-CE, light extinction values are converted into deciviews (dv), a measure for describing the ability for the human eye to perceive changes in visibility.

The USEPA guidance for estimating future year visibility levels recommends using the photochemical grid model results in a relative sense to scale the visibility current design values (DVC). The visibility DVCs are based on a 5-year average of monitored IMPROVE data centered on the typical modeling year. For this analysis, the Typical Year is 2011, so the 5-year period centered on 2011 is 2009 through 2013.

Scaling factors, called relative response factors (RRFs), are calculated from the modeling results. RRFs are applied to the DVC in order to predict future year design values (DVF) at a given monitoring location using the following equation:

$$DVF = DVC \times RRF$$

RRFs are the ratio between the model-predicted concentrations in the future year modeling scenario and the Typical Year modeling scenario. RRFs are calculated for each individual chemical component that contributes to light extinction based on the model grid cells surrounding a monitoring site.

SMAT-CE depends on IMPROVE monitors to assess visibility impacts. Notice that of the Class I areas selected for analysis, the following do not have an IMPROVE monitor within their boundaries:

- Arches NP
- Black Canyon of the Gunnison NP
- La Garita WA
- Maroon Bells-Snowmass WA
- West Elk WA
- Flat Tops WA

However, SMAT-CE is able to estimate visibility impacts at areas without a monitor by assigning a representative IMPROVE monitor following the Appendix A, Table A-2 of "Guidance for tracking

Progress Under the Regional Haze Rule[3]. Representative monitors are generally close to the Class I area.

SMAT-CE will be configured using the settings provided in **Table 4-1** and will be run with the modeling results for each of the future year 2025 modeling scenarios. Cells highlighted in **Table 4-1** represent the values recommended for this study that are different from SMAT-CE defaults. Highlighted changes are necessary to accurately incorporate the model year selected for the Typical Year and other data that is dependent on the Typical Year.

Table 4-1 SMAT-CE Configuration Settings

Option	Main category	Setting	Default	This Study
Desired Output	Scenario Name	Name		
	Forecast	Temporally-adjust visibility levels at class 1 area	Yes	Yes
		Improve algorithm	use new version	use new version
		Use model grid cells at monitors	Yes	Yes
		Use model grid cells at class 1 area centroid	No	No
	Actions on run completion	Automatically extract all selected output files	Yes	Yes
Data Input	Monitor data	File name	Classlareas_NEWIMPROVEALG_2000to2015_2017feb13_TOTAL.csv	Classlareas_NEWIMPROVEALG_2000to2015_2017april27_TOTAL.csv
	Model data	Baseline file	2002cc_EUS_PM25_sub.csv	Typical Year 2011 4-km model results[1]
		Forecast file	2020cc_EUS_PM25_sub.csv	Future year 2025 4-km model results[2]
	Using model data	Temporal adjustment at monitor	3x3	3x3
Filtering	Choose visibility data years	Start monitor year	2005	2009[3]
		End monitor year	2009	2013[3]
		Base model year	2007	2011[3]
	Valid visibility monitors	Minimum years required for valid monitor	3	3

1 Baseline file changed from default (2002) to the Typical Year (2011) modeling results.

2 Forecast file changed from default (2020) to the modeling results of the future year (2025) scenarios for this analysis. SMAT-CE was run three times changing this setting as there are three future modeling scenarios: USEPA FIP, PacifiCorp and Baseline.

3 The values for the Start, End and Base model years changed from defaults to reflect a base year centered on the Typical Year (2011) and to perform the current design value calculation with the 5-year period surrounding this year (2009 to 2013).

4.2. Reporting and Analysis

Once the SMAT-CE tool is run for each of the future year modeling results, results will be available for all Class I assessment areas requiring analysis. The values represent the visibility impairment (in deciviews) from all the sources accounted in each simulation including PacifiCorp's power plants at the Class I areas of interest. However, since all the future year scenarios were designed such that the only varying

[3] "Guidance for Tracking Progress Under the Regional Haze Rule" http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf

sources are the PacifiCorp's power plants the estimated cumulative visibility impairment can be used to quantify the effects of the different level of emissions. The results will be reported following the template presented in **Tables 4-2** and **4-3** for the 20 percent best and worst days. The tables will show the results for the 2025 Baseline (Column A), USEPA FIP (Column B) and PacifiCorp (Column C) scenarios at each of the fifteen Class I areas. The last two columns show the predicted visibility benefits from the PacifiCorp scenario relative to both the 2025 baseline (Column D) and the USEPA FIP (Column E). Also shown at the bottom row are the average visibility values from all the areas.

Table 4-2 Visibility Impact for the 2020 Baseline, USEPA FIP and PacifiCorp Scenarios on the 20 Percent Best Days

Class I area	[A] Baseline (dv)	[B] USEPA FIP (dv)	[C] PacifiCorp (dv)	[D] PacifiCorp - Baseline	[E] PacifiCorp - USEPA FIP
Grand Canyon NP					
Arches NP					
Black Canyon of the Gunnison NP					
Bryce Canyon NP					
Canyonlands NP					
Capitol Reef NP					
Mesa Verde NP					
Zion NP					
Flat Tops WA					
Mount Zirkel WA					
Maroon Bells-Snowmass WA					
West Elk WA					
La Garita WA					
Weminuche WA					
San Pedro Parks WA					
All Class I Area Average					

Table 4-3 Visibility Impact for the 2020 Baseline, USEPA FIP and PacifiCorp Scenarios on the 20 Percent Worst Days

Class I area	[A] Baseline (dv)	[B] USEPA FIP (dv)	[C] PacifiCorp (dv)	[D] PacifiCorp - Baseline	[E] PacifiCorp - USEPA FIP
Grand Canyon NP					
Arches NP					
Black Canyon of the Gunnison NP					
Bryce Canyon NP					
Canyonlands NP					
Capitol Reef NP					
Mesa Verde NP					
Zion NP					
Flat Tops WA					
Mount Zirkel WA					
Maroon Bells-Snowmass WA					
West Elk WA					
La Garita WA					
Weminuche WA					
San Pedro Parks WA					
All Class I Area Average					

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